Issues Raised by the Design of the LHC Beam Dump Entrance Window

Ray Veness / CERN

With thanks to B.Goddard and A.Presland

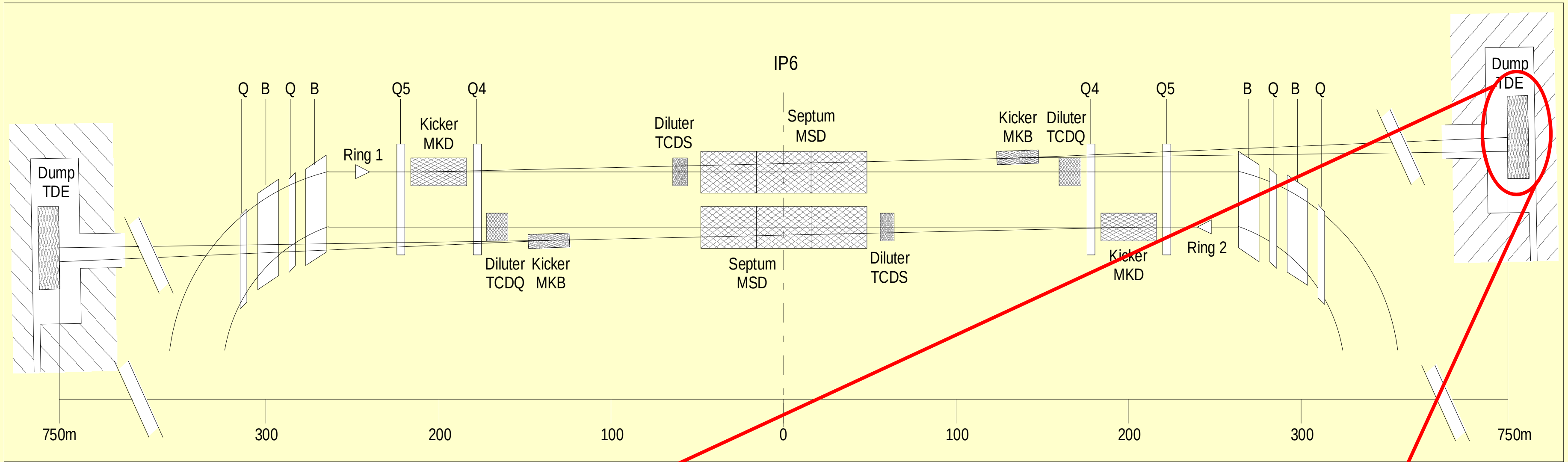
Introduction

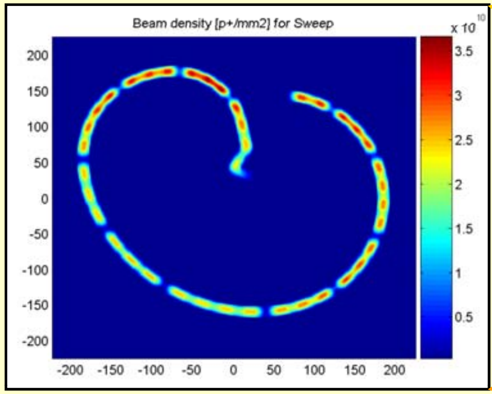
- Window vs. Absorber
  - This talk is about a window, not a collimator, so the objective is to pass the beam rather than intercept it
- However,
  - Design requires a good knowledge of the interaction between the beam and materials
  - Requirements for materials are very similar (low CTE, low Z, good high temperature strength)
  - Test and analysis requirements may yield some ‘symbiosis’
- Aim of talk
  - Explain the LHC dump entrance window design, stressing similarities and differences to collimators and absorbers
  - Discuss some open issues, which may (hopefully) have already been addressed in collimator or absorber design

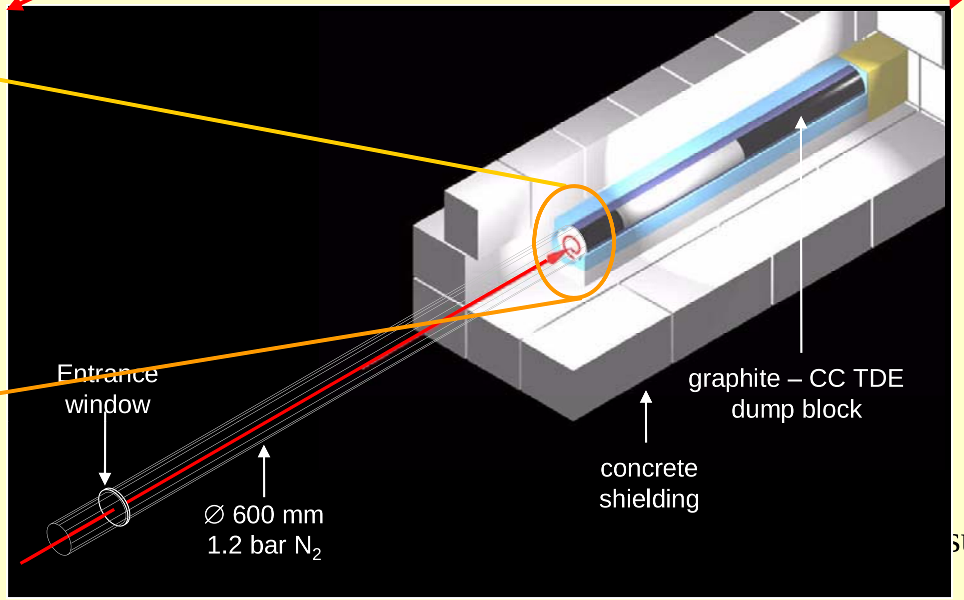
Contents

- Beam dump entrance window design
  - Overview
  - Concept
  - Analysis
- Issues
  - Energy in the system
  - Properties of carbon-carbon composite
- Final remarks

Overview of beam dump system







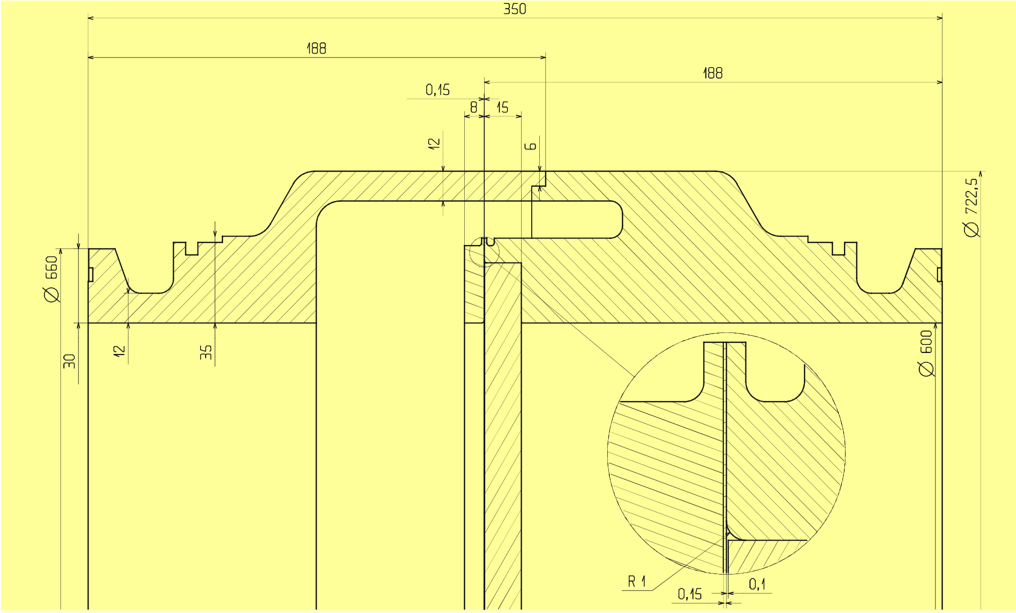
Courtesy of B.Goddard

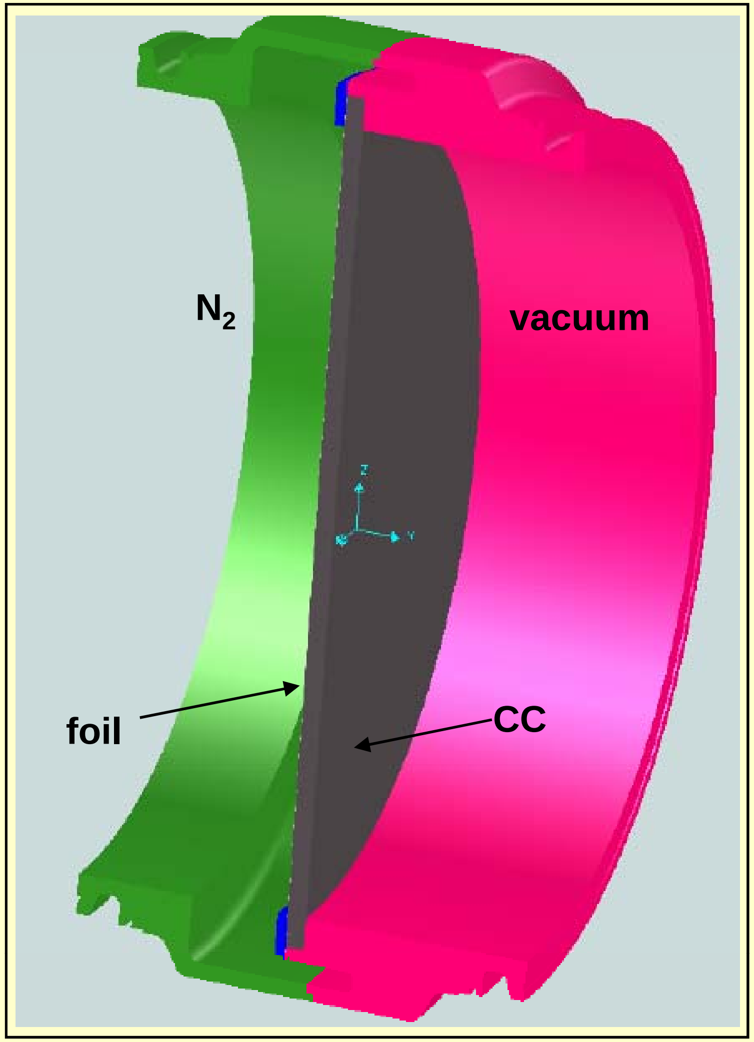
Window functionality

- Separate graphite dump core (TDE) from the dump line (TD) and LHC vacuum
  - TDE kept at 1.2 – 1.4 bar N_2 pressure
  - TD line kept at 10^{-7} mbar pressure
  - Must withstand 1.4 bar static pressure load
  - Must withstand repeated (2-4 per day) normal dump beam load for LHC lifetime
  - 600 mm clear beam aperture
  - Must not fail catastrophically for worst case beam dump dilution failure (ie, can leak, but not collapse)

Entrance Window Concept

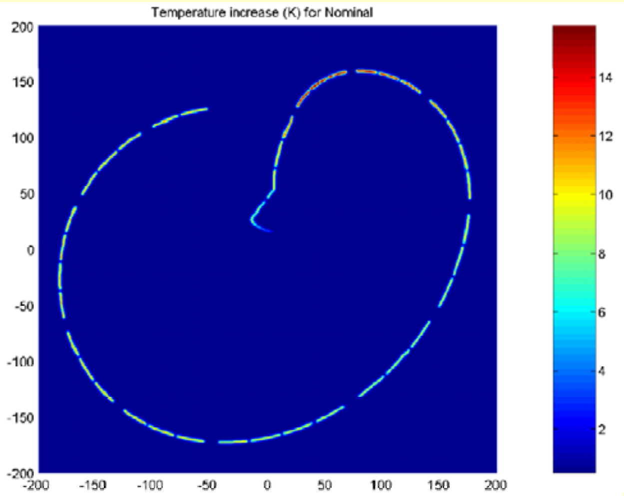
- Separate Vacuum and Mechanical requirements
  - 15mm thick C-C sheet for structure
  - Thin metal foil for leak tightness
  - Foil supported by, but free to move over the C-C



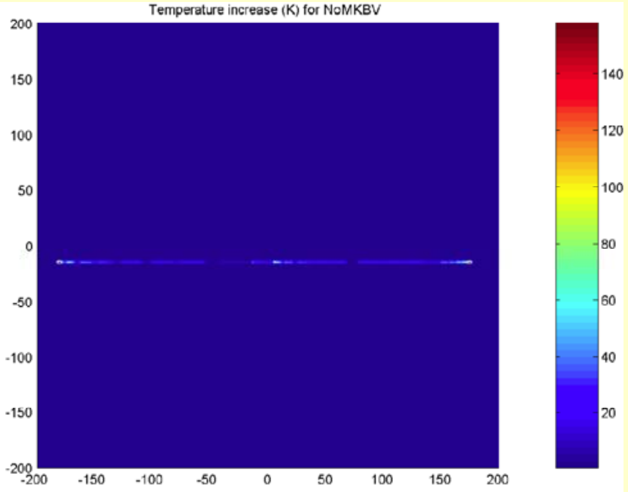


Window Design - FLUKA

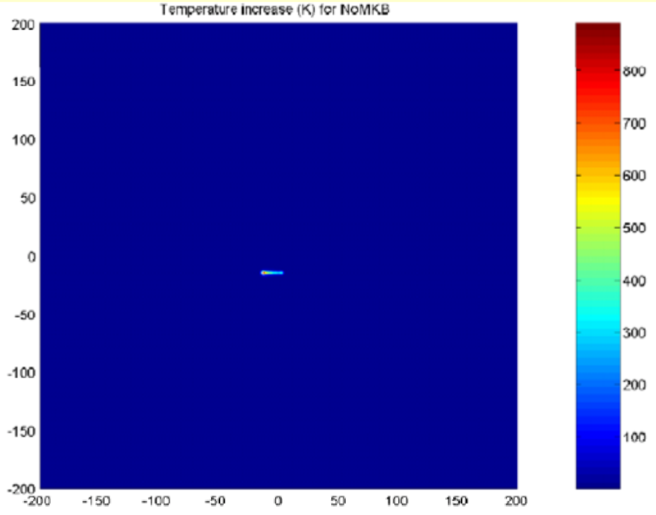
Temperature maps on the C-C window for nominal beam sweep and kicker failure scenario cases



Nominal sweep



Vertical Kicker Failure

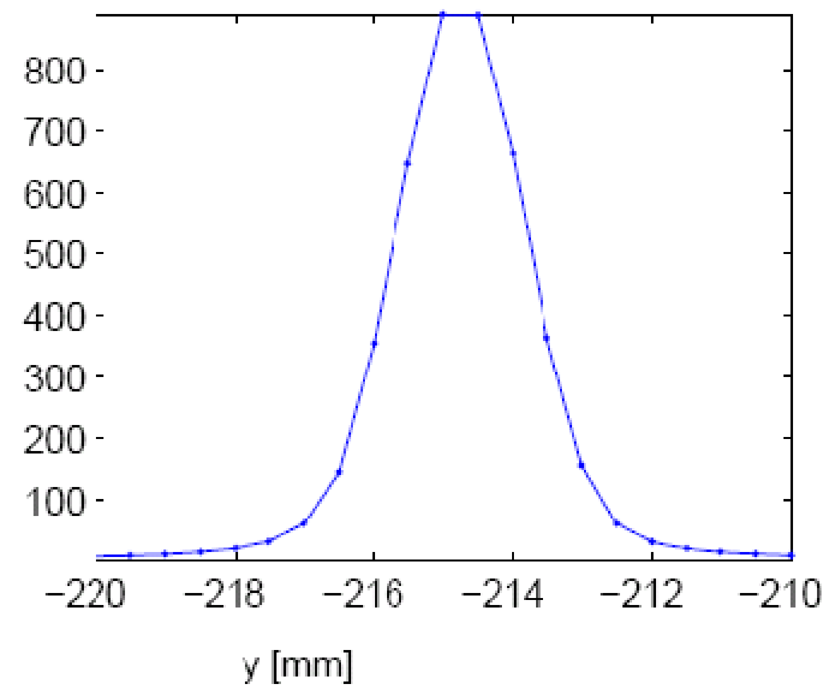


Total Kicker Failure

Data courtesy of A.Presland

Window Design - Mechanics

- Main design issues (as with collimators)
  - Very rapid temperature rise, with high peak value
  - Localised temperature step
- Axisymmetric thin window allows some simplifications
  - Thin plate – can plane stress analysis for initial analysis
  - Relatively small variation of through-thickness temperature – can neglect in some analyses
- Static mechanical loads
  - Pressure loads can be calculated analytically and superposed



Detail of transverse temperature profile for total kicker failure case in C-C plate

Design – Thermo-elastic analysis

- Analysis
  - Used bulk properties of C-C
    - Combination of low transverse CTE and low E give moderate stresses
  - Static FE analysis, with temperature profiles from FLUKA
    - Compares well with 'ideal temperature step' stress, $E\alpha\Delta T$
  - Estimated the effect of dynamic stress based on semi-analytical solution for a thin disc from Sievers [1]
    - Compares heating time with time taken for stress wave to pass the heated zone
    - Only a small (few %) dynamic stress contribution predicted by this method
    - Therefore decided not to proceed to full finite element dynamic analysis
  - Did not consider out-of-plane modes

Load case	C-C ΔT (K)	C-C Stress (MPa)
One bunch	1	0.2
Nominal	15	1
No MBKH	116	5
No MBKV	166	9
No MBK	891	57

Summary of FLUKA (temperature) and ANSYS (von Mises stress) results for the different load cases

Is this justified??

[1] P.Sievers, "Elastic stress waves in matter due to rapid heating by an intense high-energy particle beam" CERN LAB II/BT/74-2 (1974)

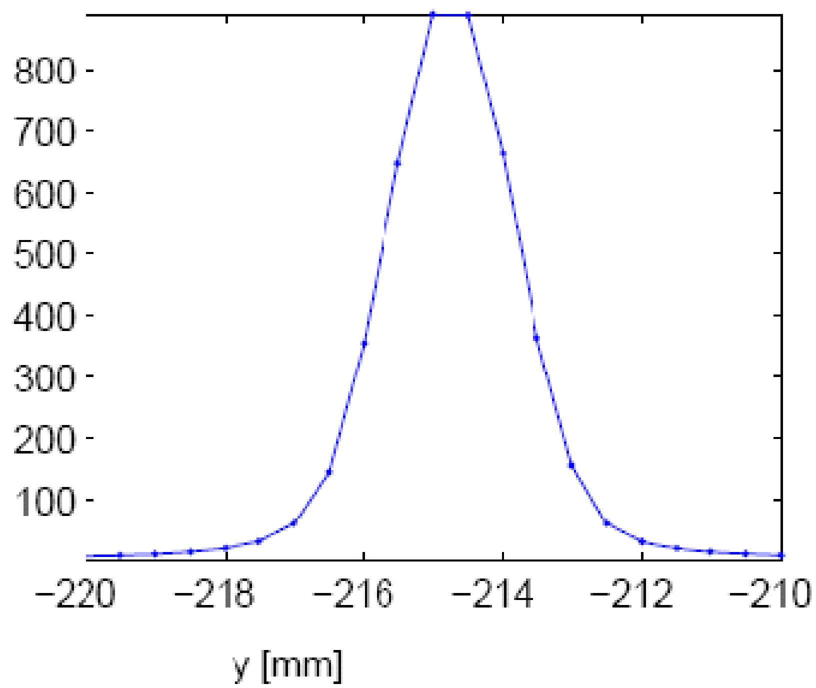
Window installed in dump line

Issues – Energy Deposition

- Some numbers
  - 362 MJ passes through window per nominal beam dumped
  - 662 J absorbed in window (from FLUKA) – 0.00018%
  - 662 J is equivalent to a 10g bullet travelling at 360 ms^{-1}
- The effect of this absorbed energy
  - Steady-state temperature rise in the window of 0.12°C
  - The C-C sees 37 times less thermo-elastic stress than stainless steel for the same temperature profile
- Concerns
  - A vast amount of energy passes through the window
    - Concequences of calculation errors are great
  - Only a minute fraction is absorbed by the window, due to the very low Z of the C-C material
    - Reliant on FLUKA output
  - This energy causes very little stress, due to the very low CTE of the C-C material
    - Reliant on material properties

Issue – C-C properties

- Window design uses a composite material that is relatively poorly qualified in an extreme environment (for the total failure case)
  - Transverse ΔT of up to 500°C/mm in C-C during total kicker failure case
  - Considering a fibre diameter of 15μm and a volume fraction 0.5, this gives a worst-case ΔT of 15°C between individual fibres
- Are bulk material properties valid?
  - What is the shear stress due to differential thermal expansion between fibre and matrix
  - Is significant damage at the fibre-matrix level possible?



Detail of temperature profile for total kicker failure case in C-C plate

Final Remarks

- Entrance window design
  - There are many similarities to collimator designs, but the analysis is made simpler by the axi-symmetric, thin plate geometry
  - The energy passing through the window is very high – it is important that the assumptions are correct
  - The design is robust for nominal conditions, but the failure scenarios raise questions about the use of bulk material properties for the composite
- Future work
  - The dynamic stress analysis should be re-visited
    - Out of plane vibrations
    - What is the best code to use?
  - Diagnostic methods for monitoring the state of the window, eg the acoustic method presented yesterday?
  - A window is potentially a good method for testing materials and qualifying codes
    - The 2-D geometry is simpler to model – verification of FE results?
    - It may be possible to insert windows 'parasitically' in fixed target lines or dump lines